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**JAKOB LAIGAARD JENSEN**  
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# Full-Scale Measurements of Offshore Platforms

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## Abstract

This paper is an extract of Jensen [49] and has been made since the contents may be of general interest when the dynamic properties of offshore platforms are considered.

During the seventies and the eighties the number of performed measurements and subsequent system identifications increased with the explosive increase in the number of offshore platforms. A survey has been performed to obtain information about how system identification is performed in practice and what practical results have been obtained. The survey includes offshore structures which have been experimentally investigated during the seventies and the eighties in international journals and conference proceedings.

An extensive survey of the available literature on the topic has been performed on the basis of more than 40 references corresponding to the experimental investigation of 34 offshore platforms. The number of investigated platforms is no doubt much larger, but a lot of the obtained information is not publicly available. E.g. the major part of all Norwegian platforms is instrumented due to authority regulations, but the number of references on those has been limited.

The performed survey is believed to reveal the typical results which can be expected from a system identification. It has not been possible to give an extensive final conclusive comment on the survey because the purpose of each instrumentation and analysis has been varying. The quality and quantity of the available references have also been very different, and furthermore, the presentation of the practical experiences varies considerably in form.

The survey has resulted in two sets of tables, the first set, tables 1 to 3, concerns the instrumentation and general information while the second set, tables 4 to 6, deals with the performed system identification methods and the obtained results. The two sets of tables are closely related but it has been necessary to divide the results of the survey into two sets of tables due to practical considerations. Anyway in the following, section 1 contains comments on mainly the first set of tables while the second set of tables is considered in section 2. A general discussion on the estimates of eigenfrequencies and damping ratios is given in sections 3 and 4, respectively.

## 1 The Performed Measurements: Tables 1-3

In tables 1a and 1b the performed instrumentations of jacket structures are given, and in table 2 and 3 the reported instrumentations of gravity and other platforms types are shown. The latter includes monopiles (monotower, tripod etc.) and different sorts of hybrid platforms. The typical instrumentation consists of 10 – 20 sensors which measure the ambient excitation and the response due to ambient excitation.

The first column of the tables refers to the instrumented structure, the name of the structure, the number of legs in the case of jacket structures, the water depth and the location of the structure are given. The locations considered are mostly the North Sea and the Mexican Gulf.

The second column refers to the period in which the structure has been instrumented. From the references attempts have been made to determine whether the structure is permanently instrumented or whether it just includes a short period. Permanent platform instrumentation is typically due to authority regulations while short periods often are directed in relation to research projects organized in joint industrial and research programmes. A short period may mean just a couple of days.

The third column gives the reported ambient excitation  $H_s$ , for which measurements have been analyzed and also tells whether an external excitation has been applied. The ambient excitation is the most frequently applied excitation source for the measured response since it is cheaper than applying an external excitation. Furthermore there will always be an extra risk with respect to the structural integrity when external excitation is applied.

The fourth column gives information about the sensors applied, the numbers and the principal types. This information is quite uncertain due to unprecise references. The following abbreviations have been applied:

- acc: accelerometers.
- mov.acc.: movable accelerometers.
- vel: velocity transducers (geophones).
- displ: displacement transducers.
- str.gau.: strain gauges.
- memb.forces.: strain gauges set-up to measure member forces.
- shock.tr.: shock transducers (typical for the response due to wave slamming).
- pres.trans.: pressure transducers (wave load).
- curr.m.: current meter.
- anom.: anemometers (wind).

Structure / Water Depth	Instr. Period	Ref.	$H_s$ / Excitation	Sensors	Data Rec.	Comment
West Sole WE,4 legs 25m, N.Sea (UK)	1978 Aug	1	0.67m ambient	16 acc.	A	removal of struct. subj: damage detect.
Ekofisk, 8 legs 70m, N.Sea (N)	1979 Jun	2	1-2m ambient/ exciters	4 points acc, str.gau.	A	authority requirements /research
Ekofisk 2/4H,4 legs 70m, N.Sea (N)	1980- 83	3	11.3m ambient	10 acc. 84 str.gau. wave radar etc	D+A	authority requirements
Valhall QP,4 legs 70m, N.Sea (N)	1980- 83	3	10.8m ambient	?	?	
Frigg DP2, 8 legs 98m, N.Sea (N)	1978- permanent	4,5	1-13m ambient	8 acc str.gau. wave-radar	A+D /research	authority requirements
SP65A, 8 legs 103m, Me.Gulf (US)  SP62C, 8 legs 103m, Me.Gulf (US)  WD152A, 8 legs 124m, Me.Gulf (US)  Eugene Island 331B, 8 legs, 82m, Me.Gulf (US)	1975- 76	6	2-3m ambient/ Snap-Back /Impulse	acc. vel. wave staff water particle velocities were measured	A	research for ambient as well as forced excitation
MP296A , 8 legs 71m, Me.Gulf (US)  SP62B, 8 legs 125m, Me.Gulf( US)  SS274, 8legs 71m, Me.Gulf (US)	1978 + 1979	7,8,9	ambient	acc. at 7 varying points	D	Joint Industry Research Project  case of damage detection
Forties Alpha,4 legs 133m,N.Sea(UK)	1980- 82	13	ambient	8 acc.	D	integrity monitoring
Amorco Montrose Alpha,8 legs 100m,N.Sea (UK)	1980- 82	13	ambient	10 acc. curr.m. wave staff	A	integrity monitoring

Table 1A. Performed measurements of jacket platforms with respect to the dynamic characteristic behaviour.

Structure / Water Depth	Instr. Period	Ref.	$H_s$ / Excitation	Sensors	Data rec.	Comment
Occ.Claymero,8 legs 127m,N.Sea (UK)	1982 May-Aug	13	ambient	55 acc. 10 str.gau. 8 wave- pres.tr.	D	integrity - monotoring
4 legs 23m, (US)	1974 visites	14	ambient	3 acc.	A	damage detection due to impact
Light Station,4 legs 25m, NY Harb. (US)	1973 temporary	15	ambient	acc.	A	structural integrity
Bullwinkle, 16 legs, 450m (US)	permanent	16	ambient	10 mov.acc. 11 str.gau. wave staffs	D (T)	
SP62C, 8 legs 100m, Me.Gulf (US)	temporary	10	4.5-5.5m /0.5-1m	17 acc.	A	damage detection
	temporary	11	ambient	2 acc.	A	research on damping
Ocean Test Struct. 22m, Me.Gulf (US)	1976- permanent	12	3m ambient	92 sensors str.gau.,wave staff,curr.m.	D	research platform subject: hydrodynamic loading
4 legs 28m Abr.Gulf	1980 April	29	Exciter	mov.acc.	D	detection of of progressive damage(research)
Platform Hope 210m Cal.coast(US)	1969- permanent	30	ambient	6 acc.	A	earthquake instrumentation
Platfrom Grace,8legs 106m Cal.coast (US)	1981- permanent	31	ambient	23 acc.	D (T)	earthquake instrumentation
Midle Ground Shoal, Platform A,Alaska(US) ditto,Platform B West Delta,124m, Me.Gulf (US)	1971 (visites)	47	ambient	9 vel. (moveable)	A	research

Table 1B. Performed measurings of jacket platforms with respect to the dynamic characteristic behaviour.



Structure / Water Depth	Instr. Period	Ref.	$H_s$ / Excitation	Sensors	Data	Comment
Gulfaks A, Condeep 134m, N.Sea (N)	1986- permanent	32,33	-9.5m ambient	16 acc.	D	authority requir. design verification, monitor. during installation
TCP2, Frigg field 103m, N.Sea (N)	1979- permanent	34,35, 36,39	13.8m ambient	56 sensors: acc. str.gau. wave-radar 32 shock tr.	D	design verification, integrity, waves
Brent B, Condeep 140m, N.Sea (N)	1975- 77	37	10.3m ambient	10 acc., 24 str.gau. 3D-wave staff	D+A	integrity, design verification
Statfjord A, Condeep 145m, N.Sea (N)	1979- permanent	38,39	ambient	8 acc. (?) 16 shock tr. 2 wave staffs + more	D+A	authority req., design verification,
Statfjord Alp N.Sea (N)		39	ambient	acc, memb.forces		

Table 2. Performed measurements of concrete gravity platforms with respect to the dynamic characteristic behaviour.

Structure / Water Depth	Instr.	Ref. Period	$H_s$ / Excitation	Sensors	Data rec.	Comment
Amoco, Monopile 30m, Me.Gulf (US) (single well)	1980 Mar 1 week visite	17-22	0.3 -2.7m ambient	2 mov.acc. 1 wave staff 1 anom. 1 curr.m.	A	research  authority requir. ?
Europlatf., Monopile 32m, N.Sea (NL) (meteorological st.)	1983 +1985 (2months)	23	ambient	4 acc. Wave staffs anom., Curr.m.	D  (T)	vibration problems
Monopile 18m, Cameroon Africa, (conduct)	1982 Jun-Jul	24	<2m ambient	3 acc. 4 str.gau. wave staff, curr.m.	D	verification of design
Lena Guyed Tower 193m Me.Gulf (US) (guided tower)	1984- permanent	25	ambient	41 load cells, 13 acc. 3 displ., 16 anom. 2 wave staffs	D+A (T)	installation, integrity monitor., research
Nordsee 30m, N.Sea (D) (hybrid)	1975 Nov. + ?	26,27	Shaker, Snap-Back with $H=1.4m$	> 6 acc. 18 str.gau.	A	structure for research
Christchurch Bay Tow. 8m, S.Coast (UK) (hybrid)	visites	28	Exciter	acc.	-	research struct., tested offshore and onshore

Table 3. Performed measurements of other platform types with respect to the dynamic characteristic behaviour.

The fifth column refers to the recording of the data: D for digital records, A for analog records and (T) for transmission of data from the platform to the main centre, typical onshore. Transmission of data has only been applied in the case of instrumentation over a long period. Transportable equipment has usually been applied when the measurements were performed during short visits. In the case of long periods of instrumentation, minicomputers are applied to control the sampling, i.e. when and for how long to sample. A current check of the sea state is applied in the case of automatic sampling. In the case of permanent instrumentation a typical sampling rule in the Norwegian sector of the North Sea seems according to Holand et al [39] to be something like:

- Storm: Complete set of records of 20 minutes every 3 hours plus a reduced set of records of 20 minutes every hour.
- Normal sea: Complete set of records of 20 minutes every 24 hours plus a reduced set of records of 20 minutes every 3 hours.

A reduced set of records means here enough data to obtain a set of key numbers such as mean values, variance, maxima, minima, check of trends in data, etc. obtained from measured signals of the response and environmental data.

The minicomputer usually includes an A/D-conversion and subsequent storage, too. However, it is not unusual also to let the minicomputer control a synchronous analog sampling since information is lost forever by the digitalization, and as backup copy which can be sampled and filtered in alternative ways.

The sixth column includes the main purpose of the instrumentation according to the given references. The purpose of the instrumentation has typically been the motives given in the previous chapter, namely an interest to improve the general knowledge about the dynamic performance and/or to monitor the integrity of the structure by observing any changes in its response. In USA permanent vibration monitoring has especially been used due to risk of earthquakes. Besides monitoring the structural behaviour it has also been a general purpose to improve the knowledge of the wave and wind loading.

## 2 The Performed Identifications: Tables 4-6

The results of the identification and interpretation of the measured data are shown in tables 4 to 6. The tables provide important structural knowledge of offshore platforms and they give a review of the possibilities of system identification.

The first column gives the information of the given structure, the water depth,  $d$  and the applied excitation either being ambient excitation or a kind of external excitation. The number of the reference, in which the results and the method for system identification have been presented, is given in brackets. From the platform name it is possible to compare the instrumentation of the platform described in tables 1 to 3 with the identification results.

Struct./d/ref. excitation	$f_i$ Hz	$\zeta_i$	$\overline{\Phi}_i$ no.	$T/f_s$ min./Hz.	Analysis type	Comment
West Sole WE,25m (1) ambient, $H_s=0.7$ m 1978	1.365 (1) 1.44 (2) 3.95 (6) $\pm 1\%$	- - -	none	20-45 / ?	FFT	peak frequencies
West Sole WE,25m ( ) ambient 1975	1.375 (1) 1.375 (2) 4.00 (6)	- - -				
Ekofisk,70m (2) shakers 1979  ditto  ambient $H_s=1-2$ m	0.66 (1) 0.70 (2) 5.41(13)  - - - -	0.035(1) 0.028(2) 0.026(3) $\pm 43\%$ 0.018(1) 0.011(2) 0.028(3) $\pm 9\%$ 0.014(1)	none	? / $f_{max}=15$	FFT	peak freq. damping by peak value  damping by bw.  damping by bw.
Ekofisk 2/4H,70m (3) ambient $H_s=11$ m	0.51(1) 0.55(2) 0.67(3)	- - -	none	-	FFT	peak freq. no influence of sea state
Frigg DP2,98m (4) ambient $H_s=1-13$ m  ditto (5)	0.625(1) 0.68 (2) 0.90 (3) - -	- - - 0.01 -0.03	none	20 /6.25  40/ 16.67	FFT  FFT	response vs. waves, peak frequencies damping vs. wave height
SP65A,103m(6) snapback/impulse	0.56(1) 0.59(2) 0.83(3)	0.027(1) 0.022- 0.027(2)	none	20/  	FFT 50 av. 0.0037Hz	zero cross. freq. +log. dec.
SP62C,103m (6) snapback/impulse  ambient ambient	0.66(1) 0.66(2) 0.96(3)  - -	0.026-0.029(1) 0.034-0.042(2)  0.010(1) 0.021-0.051	none	ditto	ditto	ditto  damp. by bw. damp. by sp.mom.
WD152A,124m (6) snapback/impulse  ambient ambient	0.61(1) 0.62(2) 1.03(3)  - -	0.022(1) - - 0.031(1) 0.024-0.049(1)	none	ditto	ditto	zero cross. freq. +log. dec. damp. by bw. damp. by sp.mom.
Eugene Isl.,82m (6)	0.52(1) 0.54(2)		none	ditto	ditto	

Table 4A. Performed analysis of jacket platforms with respect to the dynamic characteristic behaviour.

Struct.,d,ref excitation	$f_i$ Hz	$\zeta_i$	$\bar{\Phi}_i$ no.	$T/f_s$ sec/Hz	Analysis type	Comment
SS274,71m (7) ambient  ditto (8,9)	0.65-0.66(1) 0.68-0.70(2) 4.57-4.60(10)	-	(1)- (10)  (1) -(12)	240/ ?  	FFT 60 av.  	peak freq.   shape vect.
Amorco Mont.Alpha 100m (13) ambient	0.516(1) 0.535(2) 0.666(5) $\pm 1\%$	-	none	15-50 /7.66- 61.3	FFT (1024) /MEM	peak freq. MEM equals FFT results
Forties Alpha 133m (13) ambient	0.486(1) 0.569(2) 2.562(8) $\pm 1-2\%$	-	none	60/ 10.24	FFT (1024) /MEM	peak freq. MEM equals FFT results
?(US),23m (14) ambient	0.985(1) $\pm 0.5\%$	0.01	none		FFT	
Light St.,25m,(15) ambient	1.12(1) 1.46(3)	- -	none		FFT	
SP62C,100m,(10) ambient $H_s=0.5-5.5m$  ditto,(11)	0.646(1) 0.658(2) 2.62(11) ? (24) $\pm 0.8\%$	-    0.0114(1) 0.0045(2) 0.0027(3) 0.020(1) 0.021(2) 0.013(3) $\pm 15\%$	none	    32 / 6.4	FFT   MEM	peak freq. $f_i$ : $\pm 1-2\%$ due to sea state damp. by bw.
ditto,(42)  (41)	0.642(1)	0.0322(1) $\pm 62\%$ 0.0165(1) 0.0172(2) 0.0120(3)	none	16.7/ 6.4	Ran. dec. Time	zero cross., log.dec. damp. by log.dec.

Table 4B. Performed analysis of jacket platforms with respect to the dynamic characteristic behaviour.

The second column gives the two lowest estimated eigenfrequencies plus the highest eigenfrequency which has been identified corresponding to three rows per performed identification session. The number of the mode is given in brackets. This presentation shows how close the two lowest eigenfrequencies were located, and further, the highest identifiable eigenfrequency. At a fourth row the magnitude of the coefficient

of variation of the eigenfrequencies is given. The uncertainty includes in general the statistical uncertainty on the data, uncertainty of the identification method, and uncertainty due to time-varying characteristics of the structure, e.g. correlation with the sea state.

In analogy with the second column the third column gives the estimated damping ratios corresponding to the two lowest eigenmodes plus the ratio for the highest identified mode. At the fourth row the coefficient of variation is given if it has been estimated.

The fourth column gives the number of mode shapes which has been estimated. In general it is seen from the tables that eigenfrequencies are almost always identified while mode shapes rarely seem to be estimated. However, the interest in estimating the damping ratios and the mode shapes seems to be increasing. The typical case is that the three lowest eigenmodes have been identified since only those modes are sufficiently excited. In a single case up to 40 modes have been claimed to have been identified but, this is an exception where external excitation due to a shaker was applied.

Struct./d/ref. excitation	$f_i$ Hz	$\zeta_i$	$\bar{\Phi}_i$ no.	$T/f_s$ min./Hz.	Analysis type	Comment
Midle Grou.Sh.Pl. A (47), ambient	0.90(1) 1.00(2) 1.20(3) $\pm 2-3\%$	0.037(1) 0.037(2) 0.036(3) $\pm 5\%$	none	? / 31.25	FFT 15 av.	peak freq. damping by bw.
Midle Grou.Sh.Pl. B (47), ice	0.98(1) 1.09(2) 1.41(5) $\pm 1\%$	0.037(1) 0.033(2) 0.035(5) $\pm 5\%$	none	? / 31.25	FFT 15 av.	peak freq. damping by bw.
West Delta ,124m (47), ambient	0.24(1) 0.25(2) 0.40(3) $\pm 2-3\%$	0.038(1) 0.038(2) 0.035(3) $\pm 5\%$		? / 31.25	FFT 15 av.	peak freq. damping by bw.
Ocean Test Struct. 22m, (12) ambient	-	-	-	-	-	estimation of $C_D$ and $C_M$ , member forces etc.
Abr.Gulf,28m,(29) shaker	0.85- 5.0		(1)- (40)		FFT	
Platf. Hope,210m, (30),earthquake	0.59(1) 0.61(2) $\pm 1\%$	0.020-0.037(1) 0.026-0.028(2) $\pm 10-25\%$	none		FFT	peak freq. damp. by. sp.mom.

Table 4C. Performed analysis of jacket platforms with respect to the dynamic characteristic behaviour.

Struct.,d,ref. Excitation	$f_i$ Hz	$\zeta_i$	$\bar{\Phi}_i$ no.	$T/f_s$ sec./Hz	Analysis type	Comment
Gullfaks A,134m,(33) ambient	0.438(1) 0.533(2) 0.753(4) $\pm 2\%$	0.015(1) 0.014(2) 0.021(4) $\pm 8-30\%$	(1)- (4)	20/ 2.3-11.4	ARMA	identific. from ARMA- model
TCP2,103m,(34) ambient, $H_s < 13.8\text{m}$ 1979	0.647(1) 0.760(2) 1.07(3) $\pm 2-3\%$	-	none	20/	FFT	peak freq. + response vs. waves
extra deck mass(31%)	0.593(1) 0.675(2)					
ditto, (35) 1980,storm	0.605(1) 0.645(2) 0.765(3)	-		20/	MEM	peak freq.
ditto, (35) 1981,storm	0.605(1) 0.600(2)			20/	MEM	identific. of stiffness and mass
extra deck mass(31%) (36) $H_s < 12\text{m}$	0.670(3)			20/ 4	FFT	member force vs. waves
Brent B,140m,(37) ambient, $H_s < 10.3\text{m}$	0.56(1) 0.58(2) 0.84(3)	-	(1)- (3)	20/	FFT	peak freq. +identific. of stiffness
Statfjord A,145m,(38) ambient, $H_s < 10.7\text{m}$	0.43(1) 0.43(2) 1.58(8)	0.015(1) 0.02(2) $\pm 50\%$	(1)- (3)	20/ 8	ARMA	identific. by ARMA, estimates vs. waves stifn. identific.

Table 5. Performed analysis of concrete gravity platforms with respect to the dynamic characteristic behaviour.

If possible the fifth column gives the basic length of the applied time series plus the sampling frequency or alternatively the maximum frequency kept in digitally converted signals.

The most typical record length seems to be 20 minutes. This record length is thought to be due to the need for limiting the amount of data when measurements are performed over a longer period. Furthermore, the record length is also limited by the fact that system identification in general assumes data due to stationary random processes. The wave excitation process will only be quasi stationary within shorter periods of time. The sampling frequency has to be sufficiently high to ensure an accurate representation of the continuous signals on digital form. On the other hand, the amount of data must be limited. The result is that filtering and synchronous sampling with different sampling frequencies are widely applied for the purpose of getting information about a given frequency region in the measured response and excitation processes.

Struct.,d,ref. Excitation	$f_i$ Hz	$\zeta_i$	$\bar{\Phi}_i$ no.	$T/f_s$ sec./Hz	Analysis type	Comment
Monopile,30m,(19) ambient	0.3234(1) 0.3237(1)	0.0104(1) 0.0111(1)	none	32/ 6.4	MEM	curvefit peak freq.+ damp.by bw.
ditto	0.3228(1) 0.3234(1)	0.0227(1) 0.0244(1)		32/ 6.4	FFT	curvefit peak freq.+ damp.by bw.
ditto, (18,21)	0.32(1) 1.20(2) 3.06(3)		(1)- (2)	80/ 6.4	MEM	peak freq.
ditto, (17,20) $H_s=0.3-1\text{m}$	0.325(1) 0.327(2)	0.011(1) 0.013(2) $\pm < 14\%$	none		MEM	peak freq., damp. by bw.
ditto, (17,20) $H_s=1.7-2.7\text{m}$	0.323(1) 0.328(2)	0.010(1) 0.014(2) $\pm < 20\%$	none		MEM	ditto
ditto, (17,20) $H_s=0.7-1.3\text{m}$	0.323(1) 0.327(2)	0.009(1) 0.011(2) $\pm < 27\%$	none		MEM	ditto
ditto, (22)						identific. of mass+stiffness
ditto, (43)	0.326(1)	0.0095(1) $\pm < 9\%$	none		Ran.- dec.	Ibrahim time domain method
Monopile(NL),32m (23),ambient	0.382(1)	0.015(1)	none		FFT	peak freq., damp. by bw.
Monopile(Africa) 18m,Cameroon ambient, $H_s=2\text{m}$	0.41(1) 2.58(2) 5.00(5)	-	(1)- (5)	40/ 20	FFT	shape vect.  $C_D$ and $C_M$ estimated
Nordsee,hybrid ,30m (26,27) shakers and $H=1.4\text{m}$	2.22(1) 3.34(2) 4.03(3) $\pm < 3.5\%$	0.028(1) - 0.023(3) $\pm < 30\%$	none	75	FFT (0.02Hz)	curvefit, also mass estimation
Christch.Bay,hybrid 8m,(28) shakers	2.3-2.4(1) 3.3-4.9(2)	0.02-0.04(1) 0.01-0.03(2)	none		FFT	peak freq., damp. by bw. off-/onshore

Table 6. Performed analysis of other platform types with respect to the dynamic characteristic behaviour.

The sixth column shows the kind of signal analysis which has been reported in each reference:

- FFT (Fast Fourier Transformation) which is further described in chapter 5 and partly also in chapter 7 in Jensen [49].
- MEM (Maximum Entrophy Method) which is described in chapter 8 in Jensen [49].
- Random dec. (random decrement technique) which is described in chapter 5 and partly in chapters 6 and 7 in Jensen [49].
- ARMA (Auto-Regressive Moving Average) which is described in chapter 8 in Jensen [49].

The first two kinds of analyses are usually applied in the frequency domain while two latter are methods in the time domain. The first and the third method are methods which in system identification are combined with some kind of curvefitting algorithm, while the second and the fourth method are methods which provide parametric expressions for e.g. the eigenfrequencies and the damping ratios.

In the case of a performed FFT analysis any available information of the number of averages, the resolution or the number of frequency points is also given in the sixth column.

In the seventh column comments have been made on the system identification and any applied curvefitting algorithm. The applied curvefitting algorithms include:

- Peak freq. (frequency) which is identification of the eigenfrequencies from the peak frequencies of the measured response spectra.
- Damping by bw. (bandwidth) which is identification of the damping ratio from the width of the resonance peak in the measured response spectra, see chapter 7 in Jensen [49].
- Zero cross. freq. (zero crossing frequency) which is identification of the eigenfrequency from the zero crossing period of the measured response process, see chapter 7 in Jensen [49].
- Log. dec. (logarithmic decrement) which is identification of the damping from a free decay, see chapter 7 in Jensen [49].
- Damp. by sp.mom. (damping by spectral moments) which is identification of the damping ratio from the three lowest spectral moments of the response spectrum, see chapter 7 in Jensen [49].
- Shape vect. (shape vectors) which is identification of the eigenfrequencies and the mode shapes from a curvefit on a measured response spectrum, see chapter 7 in Jensen [49].
- Ibrahim time domain method which is a method for identification of the modal parameters from a free decay, see chapter 7 in Jensen [49].

The more general curvefitting algorithms which have been applied in some references are discussed in chapter 7 in Jensen [49].



### 3 The Eigenfrequency Estimates

From the estimated eigenfrequencies of jacket platforms it is seen that the first eigenfrequency is clearly correlated with the water depth, see figure 1. A similar observation can be made for tall buildings. Ellis [44] observed from a review of experimental and numerical analysis of 163 buildings that the most reliable calculated estimate of the first eigenfrequency was obtained from the expression  $f_1 = \frac{46}{h}$  Hz obtained from a fit of the experimental estimated eigenfrequency. It was reported that the uncertainty of estimates obtained by numerical analysis by finite element methods were about 50%. The uncertainty of the identified eigenfrequency from measurements typical lies in the range of 1 – 2%. This case for tall buildings clearly illustrates the importance of the concept of system identification in structural design.

One reason for the uncertain prediction of eigenfrequency is probably that the mass distribution of structures is more uncertain than commonly expected. Snedden [45] has reported that already at the construction site of offshore structures there is an uncertainty of the masses of construction elements about 10 – 15% in spite of a performed weight control. This source of uncertainty will tend to give an underestimation the total mass since modification of the design during construction will in general tend to give an increase of the steel consumption because steel is relatively inexpensive. This source plus the uncertainty of structural modification during the structural lifetime may mean an uncertain of the mass distribution of about 20% leading to an uncertainty prediction of the eigenfrequencies.

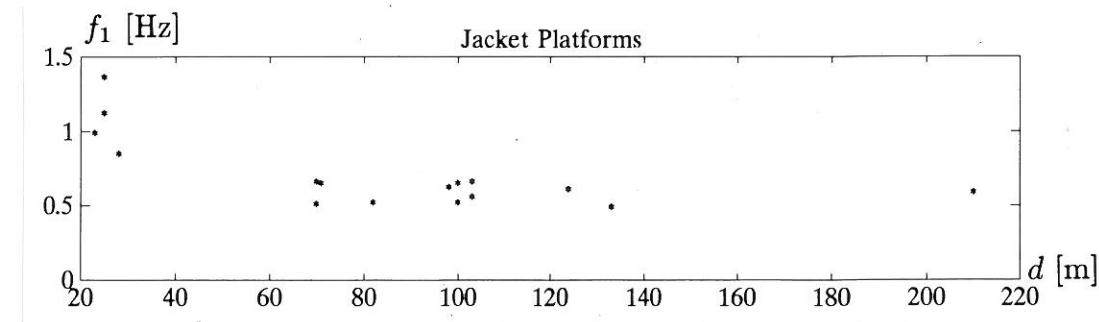


Figure 1. Identified first eigenfrequency of jacket platforms versus the water depth.

Only a small number of identified eigenfrequencies has been found on gravity platforms. However, the same correlation w.r.t. the water depth is expected to exist. The first eigenfrequency seems to lie in the range 0.30 – 0.65 Hz for water depths 100 – 150 m.

Offshore structures such as monopiles (monotowers, single standing conductors, tripods etc.) are becoming increasingly popular structural concepts for unmanned

platforms, however, the number of such platforms are still small and thus also the number of performed measurements. However, some cases of system identification of such platforms have been found. At a water depth about 30 – 40 m, the first eigenfrequency will typically lie in the range 0.30 – 0.40 Hz.

Structural changes will also affect the eigenfrequencies. A practical example was given by the TCP2 condeep platform in the Norwegian part of the North Sea, see tables 3 and 5. Here, a 31% increase in the deck mass led to a 13% decrease in some of the lowest eigenfrequencies. Furthermore, during a period of 5 years some eigenfrequencies dropped about 10%. Thus an offshore structure cannot be considered to be a time independent system over several years.

For an SDOF system the first eigenfrequency is given by  $f_0 = 2\pi\sqrt{\frac{k}{m}}$  which leads to the sensitivity relations of the eigenfrequency w.r.t. the mass and the stiffness:

$$\frac{df_0}{f_0} = -\frac{1}{2} \frac{dm}{m} \quad (1)$$

$$\frac{df_0}{f_0} = \frac{1}{2} \frac{dk}{k} \quad (2)$$

The observed decrease in the eigenfrequency in the Norwegian case is seen to have the same magnitude which was to be expected for an SDOF system. Thus, since it is the lowest eigenmodes which are excited in practice, significant stiffness and mass changes associated with the lowest eigenmodes will be observed as significant changes in the lowest eigenfrequencies, while structural changes affecting the performance of the higher modes will in general not be possible to detect, since those modes are not dynamically excited.

## 4 The Damping Estimates

The estimated damping ratios in the tables do not seem to be correlated with the water depth. Instead they seem to depend upon the type of structure. Neither does the damping ratio seem to depend upon the eigenmode considered. This means that in general offshore structures will not be proportionally damped.

An analysis of all identified damping ratios of jacket platforms for all modes shows that the damping typically lies between 1–3% with a mean of 2.1% and a coefficient of variation of 46%, see figure 2.

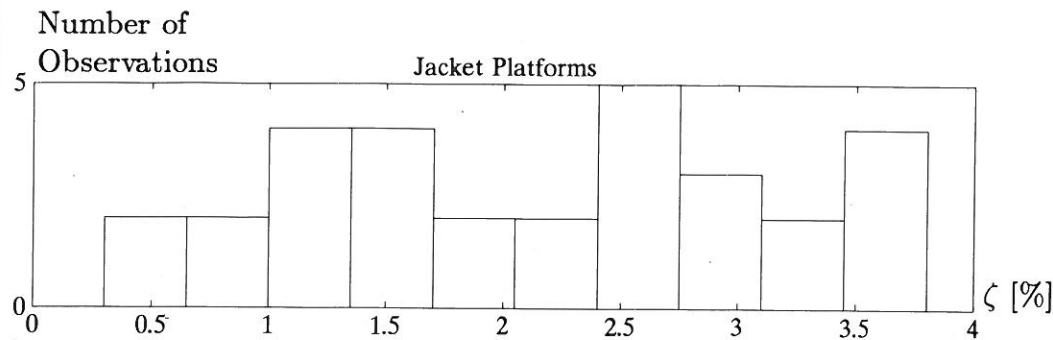


Figure 2. Histogram of identified damping ratios for jacket platforms including all identified modes.

For monopile structures the damping may be a little smaller with a mean of 1.3% and a coefficient of variation of 37%. For gravity platforms the damping seems to lie in the range 1.4 – 2.1%. However, only a few structures of the two structural types have been identified.

The estimated magnitude of the damping ratios can be compared with the recommendation of Det Norske Veritas [48] as shown in table 7. The damping values from the Det Norske Veritas include only structural damping. A contribution of the magnitude 0.05 – 0.02 may be added due to the surrounding water. The damping in the foundation is not explicitly evaluated in the reference. It is seen that the obtained damping from the review is in general larger than the given values for the structural damping. The damping contribution from the foundation and water seems to be rather uncertain according to the rules of Det Norske Veritas and it is clear that the damping is in general underestimated if the design basis only includes the structural damping given by e.g. Det Norske Veritas. This will be a conservative element in the design basis and thus lead to less optimal structures.

Estimates due to	Jacket platforms	Monopile platforms	Gravity platforms
Review	2.1%	1.3%	1.4-2.1%
D.N.V.	1%	1%	1-2 %

Table 7. Damping ratios from the review and from the rules of Det Norske Veritas (D.N.V.) [48].

The review has shown that a priori knowledge of the damping ratios based upon the tables is coupled with a coefficient of variation of the damping ratio in the range of 50% while a performed identification on a given structure may reduce the uncertainty of the damping ratio down to a magnitude of about 10%. I.e. the case with a monopile platform shows that if a single analysis is disregarded the coefficient of variation due to different analysis is as low as 7% for the first damping ratio and 12% for the second damping ratio. Thus, a substantial reduction in the uncertainty of damping can be obtained by identification of a given structure.

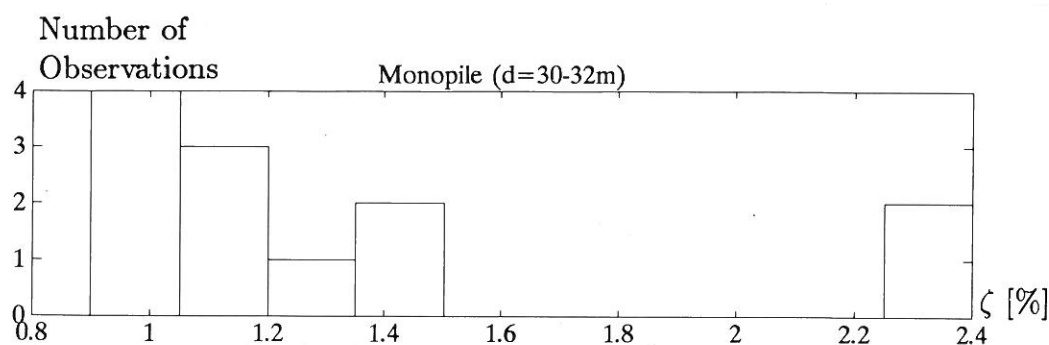


Figure 3. Histogram of the identified damping ratios of all modes for investigated monopile structures.

## 5 Conclusion

The performed survey has revealed the existing practice and stage of system identification of offshore platforms.

The results of the survey of performed system identifications show that the eigenfrequencies and the damping ratios can be estimated of a certain accuracy for a given offshore platform which will provide a much better basis than the general a priori knowledge that e.g. Det Norske Veritas' rules represent. The latter will typically be the knowledge which can be extracted from a survey of the performed kind which clearly illustrates how uncertain the a priori knowledge of especially damping is, and it is thus also pointed out how conservative the design basis must be to ensure the reliability of the structures.

The aspect has been illustrated by Jeary and Ellis [46] who have investigated the effect of reducing the uncertainty of predicted response by employing results of system identification. Considering an SDOF system harmonically excited by its eigenfrequency, the displacement amplitude is given by:

$$X(f_0) = \frac{F(f_0)}{4\pi^2 f_0^2 m 2\zeta_0} \quad (3)$$

which leads to a simple relation between the uncertainty of the predicted response and sources of uncertainty:

$$\frac{dX(f_0)}{X(f_0)} = \frac{dF(f_0)}{F(f_0)} - \frac{dm}{m} - \frac{d\zeta_0}{\zeta_0} - \frac{2df_0}{f_0} \quad (4)$$

Assuming the following uncertainties at the design stages:

$$f_0 : \pm 50\% \quad m : \pm 20\% \quad \zeta_0 : \pm 100\% \quad F(f_0) : \pm 20\%$$

the uncertainty of displacement amplitude at resonance becomes:  $\pm 240\%$ , while a performed system identification, if it has led to the following reduced uncertainties:

$$f_0 : \pm 0.1\% \quad m : \pm 20\% \quad \zeta_0 : \pm 10\% \quad F(f_0) : \pm 20\%$$

leads to an uncertainty of  $\pm 50\%$  of the predicted response.

This example illustrates together with the discussion in this and the previous chapter, what can be gained by system identification of offshore structures.

## 6 References

- [1] Kenley, R. M. and C. J. Dodds, "West Sole WE Platform: Detection of Damage By Structural Response Measurements", OTC 3866, Offshore Technology Conference, Houston, USA, 1980.
- [2] Gundy, W. E., T. D. Schartcon and R. L. Thomas, "Damping Measurements of An Offshore Platform", OTC 3863, Offshore Technology Conference, Houston, USA, 1980.
- [3] Langen, I., N. Spidsøe, R. L. Bruce and J. W. Heaver, "Measured Dynamic Behaviour of North Sea Jacket Platform", OTC 4655, Offshore Technology Conference, Houston, USA, 1984.
- [4] Ansquer, P. F. and R. S. Carton, "Field Measurements of Correlation Between Waves and Platform Response Versus Significant Wave Height and Wave Direction", OTC 3797, Offshore Technology Conference, Houston, USA, 1980.
- [5] Olagnon, M. and M. Prevosto, "The Variation of Damping Ratios with Sea Conditions for Offshore Structures Under Natural Excitation", OTC 4654, Offshore Technology Conference, Houston, USA, 1984.
- [6] Ruhl, J. A., "Observed Platforms: Observed Behavior and Comparaisons with Theory", OTC 2553, Offshore Technology Conference, Houston, USA, 1976.
- [7] Duggan, D. M., E. R. Wallace and S. R. Caldwell, "Measured and Predicted Vibrational Behaviour of Gulf of Mexico Platforms", OTC 3864, Offshore Technology Conference, Houston, USA, 1980.
- [8] Burke, B. G. and N. R. Sosaian, "Analysis of Ambient Vibration Data By Multiple Shape Vectors", OTC 4284, Offshore Technology Conference, Houston, USA, 1982.
- [9] Burke, B. G. and P. M. Safaie, "Characterization of Ambient Vibration Data By Response Shape Vectors", OTC 3862, Offshore Technology Conference, Houston, USA, 1980.
- [10] Coppolino, R. N. and S. Rubin, "Detectability of Structural Failures in Offshore Platforms By Ambient Vibration Monitoring", OTC 3865, Offshore Technology Conference, Houston, USA, 1980.
- [11] Cambell, R. B. and J. K. Vandiver, "The Estimation of Natural Frequencies and Damping Ratios of Offshore Structures", OTC 3861, Offshore Technology Conference, Houston, USA, 1980.
- [12] Haring, R. E., "Status of the Ocean Test Structure Program", in *Safety of Structures Under Dynamic Loading*, vol. 2, ed I. Holand et al. Tapir, 1978.
- [13] Nataruja, R., "Structural Integrity Monitoring in Real Seas", OTC 4538, Offshore Technology Conference, Houston, USA, 1983.
- [14] Vandiver, J. K., "Detection of Structural Failures of Fixed Platforms By Measurements of Dynamic Response", *J. of Petroleum Technology*, Mar. 1977.
- [15] Wojnarowski, M. E., S. G. Stiansen and N. E. Reddy, "Structural Integrity Evaluation of A Field Platform Using Vibration Criteria", OTC 2909, Offshore Technology Conference, Houston, USA, 1977.
- [16] Swanson, R. C. and G. D. Baker, "The Bullwinkle Platform Instrumentation System", OTC

- 6052, Offshore Technology Conference, Houston, USA, 1989.
- [17] Cook, M. F., "Damping Estimation, Response Prediction and Fatigue Calculation of An Operational Single Pile Platform", M.Sc. Thesis, Massachusetts Inst. of Techn., USA, 1982.
  - [18] Briggs, M. J., "Multichannel Maximum Entropy Method of Spectral Analysis Applied To Offshore Structures", Thesis, Massachusetts Inst. of Techn., USA, 1981.
  - [19] Xinsen, L. and J. K. Vandiver, "Damping and Natural Frequency Estimation Using the Least Pth Optimization Technique", OTC 4283, Offshore Technology Conference, Houston, USA, 1982.
  - [20] Cook, M. F. and J. K. Vandiver, "Measured and Predicted Dynamic Response of A Single Pile", OTC 4285, Offshore Technology Conference, Houston, USA, 1980.
  - [21] Briggs, M. J. and J. K. Vandiver, "Multichannel Maximum Entropy Method of Spectral Analysis Applied To Offshore Platforms", OTC 4286, Offshore Technology Conference, Houston, USA, 1982.
  - [22] Sunder, S. S. and R. A. Sanni, "Foundation Stiffness Identification for Offshore Structures", Applied Ocean Research 1984, vol. 6, no. 3, CML Publisher, 1984.
  - [23] Peters, H. and H. Boonstra, "Fatigue Loading On A Single Pile Platform Due To Combined Action of Waves and Currents", Behaviour of Offshore Structures, BOSS 88, 1988.
  - [24] Barnouin, B., M. Olagnon, O. Guillermin, R. Nerzic and M. Cahg, "Comparison of the Prediction with Full Scale Measurements On A Free Standing Conductor Pile", Proc. of the 3rd Int. Offshore Mechanics and Artic Eng. Symp., vol.2, American Society of Mechanical Engineers, New Orleans, USA, 1984.
  - [25] Lamb, W. C. Jr., H. C. Hibbard, A. L. Jansen, W. A. Koorner and R. H. Rothberg, "Instrumentation for Monitoring Behaviour of Lena Guyrf Tower", OTC 4684, Offshore Technology Conference, Houston, USA, 1984.
  - [26] Kolb, M., W., D. Longree and A. Westram, "Untersuchungen von Eigenschwingungen der Forschungsplattform Nordsee bei natuerlicher und kunstlicher Anregung", VDI-Schwingungstagung, VDI-Berichte 269, Verein Deutsche Ingenieure, Germany, 1976.
  - [27] Natke, H. G. and H. Schulze, "Parameter Adjustment of A Model of An Offshore Platform From Estimated Eigen Frequencies Data", J.Sound and Vibration, vol. 77 (2), 1981.
  - [28] Ellis, B. R., "The Dynamic Characteristics of An Offshore Structure, Both Before, and After A Structural Failure", in Safety of Structures Under Dynamic Loading, vol.2, ed. I.Holand et al., Tapir, 1978
  - [29] Crohas, H. and P. Lepert, "Damage Detection Monitoring Method for Offshore Platforms Is Field Tested", Oil & Gas Journal, Feb. 22, OGJ Report, 1982.
  - [30] Vanmarcke, E. H. and R. N. Tascone, "Estimation of Dynamic Characteristics of Deep Water Ocean Tower Structures", Report no. MITSG72-12, Massachusetts Inst. of Techn., USA, 1972.
  - [31] Chen, J., R. R. Ullmann and A. B. Mason, "Measurement of Earthquake Ground Acceleration and Structural Response", OTC 6172, Offshore Technology Conference, Houston, USA, 1989.

- [32] Lokna, T. and K. A. Nyhus, "Damping and Natural Frequencies During Towout and Installation of the Gullfaks A Platform", OTC 5786, Offshore Technology Conference, Houston, USA, 1988.
- [33] Hoeklie, M. and O. E. Hansteen, "Measured and Predicted Dynamic Behaviour of the Gullfaks A Platform", OTC 5785, Offshore Technology Conference, Houston, USA, 1988.
- [34] Ansquer, P. F., S. A. Antaleusky, E. Hjelde and G. Agnello, "Field Measurement of Platform Behaviour, Comparison with Design, and Long Term Monitoring of Response Stability After Three Years of Service", J.Energy Resources Technology vol.106, Dec., American Society of Mechanical Engineers, Dec. 1984.
- [35] Thebault, J., L. Robberstad, I. Langen, G. Agnello, I. Doucet and R. Nerlic, "in Service Response Analysis of Two Fixed Offshore Platforms", Behaviour of Offshore Structures BOSS84, Elsevier Science Publishers, 1984.
- [36] Spidsoe, N. and B. A. Leite, "Statistical Properties of Measured Wave-Induced Section Forces in Gravity Platform Shaft", OTC 5415, Offshore Technology Conference, Houston, USA, 1986.
- [37] Hansteen, O. E., E. Dibiago and K. H. Andersen, "Performance of the Brent B Offshore Platform", Proc. 10th Int. Conf. On Soil Mechanics and Foundation Engineering, vol. 1, Stockholm, Sweeden, 1981.
- [38] Spidsoe, N. and O. Skjaastad, "Measured Storm-Induced Variations of the Soil- Structure Interaction Properties of A Gravity Platform", OTC 5410, Offshore Technology Conference, Houston, USA, 1987.
- [39] Holand, I., S. Berg and G. Beck, "Environmental and Structural Instrumentation of Platforms On the Norwegian Continental Shelf", 2nd Int. Conf. On Behaviour of Offshore Structures, BOSS79, London, UK, 1979.
- [40] Eide, O., K. H. Andersen and T. Cunne, "Observed Foundation Behaviour of Concrete Gravity Platforms Installed in the North Sea 1973-1978", Appl. Ocean Research vol.3, no.3, 1981.
- [41] Ruhl, J. A., "Forced Vibration Tests of A Deepwater Platform", OTC3514, Offshore Technology Conference, Houston, USA, 1979.
- [42] Nasir, J. and S. S. Sunder, "An Evaluation of the Random Decrement Technique of Vibration Signature Analysis for Monitoring Offshore Platforms", Research Report R82-52, Dept. of Civil Eng., Massachusetts Inst. of Techn., USA, 1982.
- [43] Longo, P., "Vibration Monitoring of Offshore Platforms Using the Ibrahim Time Domain Modal Identification Technique", M.Sc. Thesis, Dept. of Ocean Eng., Massachusetts Inst. of Techn., USA, 1982.
- [44] Ellis, B. R., "An Assessment of the Accuracy of Predicting the Fundamental Natural Frequencies of Buildings and the Implification Concerning The Dynamic Analysis of Structures", Proc. of the Institution of Civil Engineers, part 2, vol. 69 Sept., UK., 1980.
- [45] Snedden, C. N., "Weight Control of Offshore Structures", Offshore Research Focus, no. 25, June 1981.
- [46] Jeary, A. P. and B. R. Ellis, "The Accuracy of Mathematical Models of Structural Dynamics",



- in Design for Dynamic Loading - the Use of Model Analysis, ed. G.S.T.Armer and F.K.Garus Construction Press, London, UK, 1982.
- [47] Earle, E. N and W. L. Mandery, "Deterministic of Dynamic Characteristics of Offshore Platforms From Random Vibrations", OTC 1840, Offshore Technology Conference, Houston, USA, 1973.
- [48] "Rules for the Design, Construction and Inspection of Offshore Structures, 1977, Appendix G, Dynamic Analysis", (reprint with corrections) , Det Norske Veritas, OSLO, 1982.
- [49] Jensen, J. L., "System Identification of Offshore Platforms", (Ph.D. thesis to be published in 1990), Paper in the series of Fracture and Dynamics, Institute of Building Technology and Structural Engineering, University of Aalborg, Denmark, 1990.



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